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(54) **HIGH-SIDE SYNCHRONOUS RECTIFIER CIRCUITS AND CONTROL CIRCUITS FOR POWER CONVERTERS**

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H02M 3/335 (2006.01)

(52) **U.S. Cl.**
USPC 363/21.14; 363/21.13

(58) **Field of Classification Search**

USPC 363/21.06, 21.14, 127, 21.05, 21.13; 323/288

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,206,208 B1 * 4/2007 Hsu et al. 363/21.06
7,440,298 B2 * 10/2008 Yang 363/89

* cited by examiner

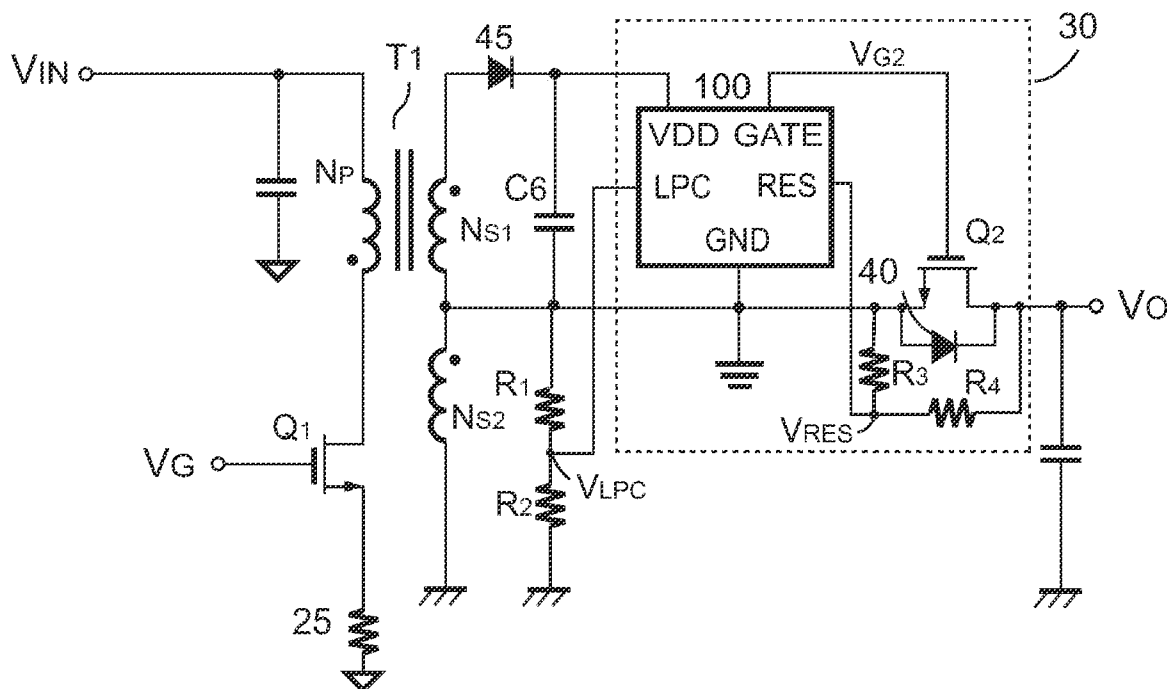
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(57) **ABSTRACT**

A control circuit for a switching power converter is provided. The control circuit is installed between a secondary side and an output of the power converter and coupled to control a switching device. The control circuit includes a linear predict circuit, a reset circuit, a charge/discharge circuit, and a PWM circuit. The linear predict circuit is coupled to receive a linear predict signal from the secondary side for generating a charging signal. The reset circuit is couple to receive a resetting signal for generating a discharging signal. The charge/discharge circuit is coupled to receive the charging signal and the discharging signal for generating a ramp signal. The PWM circuit is coupled to receive the linear predict signal for enabling a switching signal and receive the ramp signal for resetting the switching signal.

8 Claims, 6 Drawing Sheets



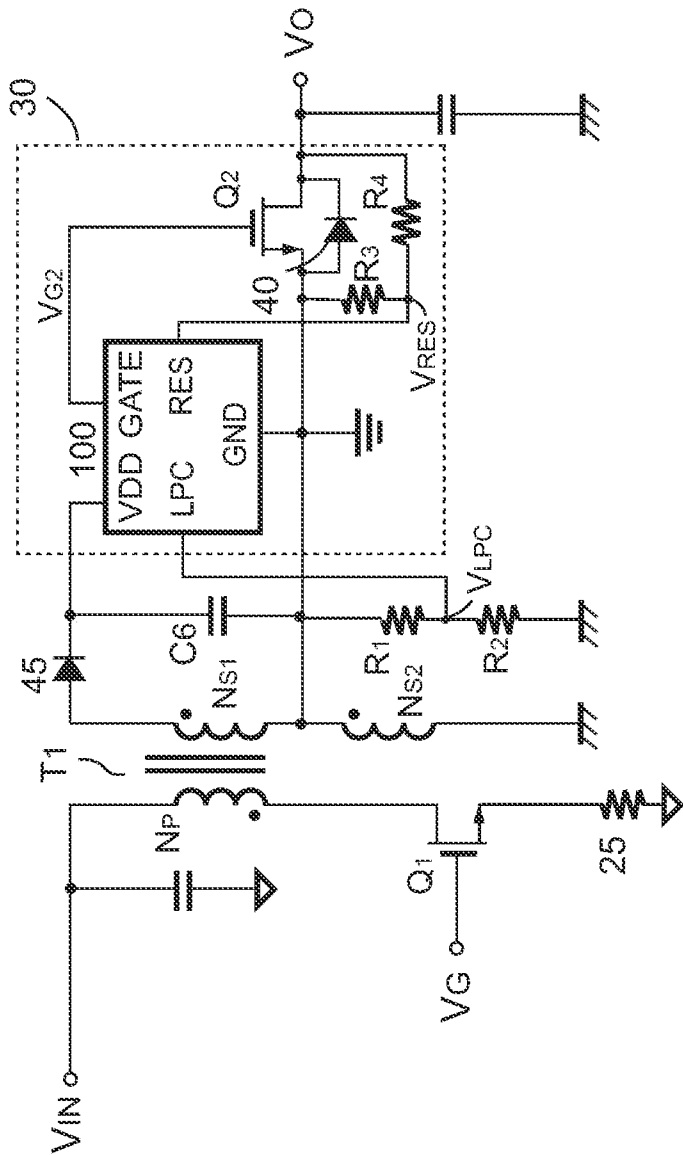


FIG. 1

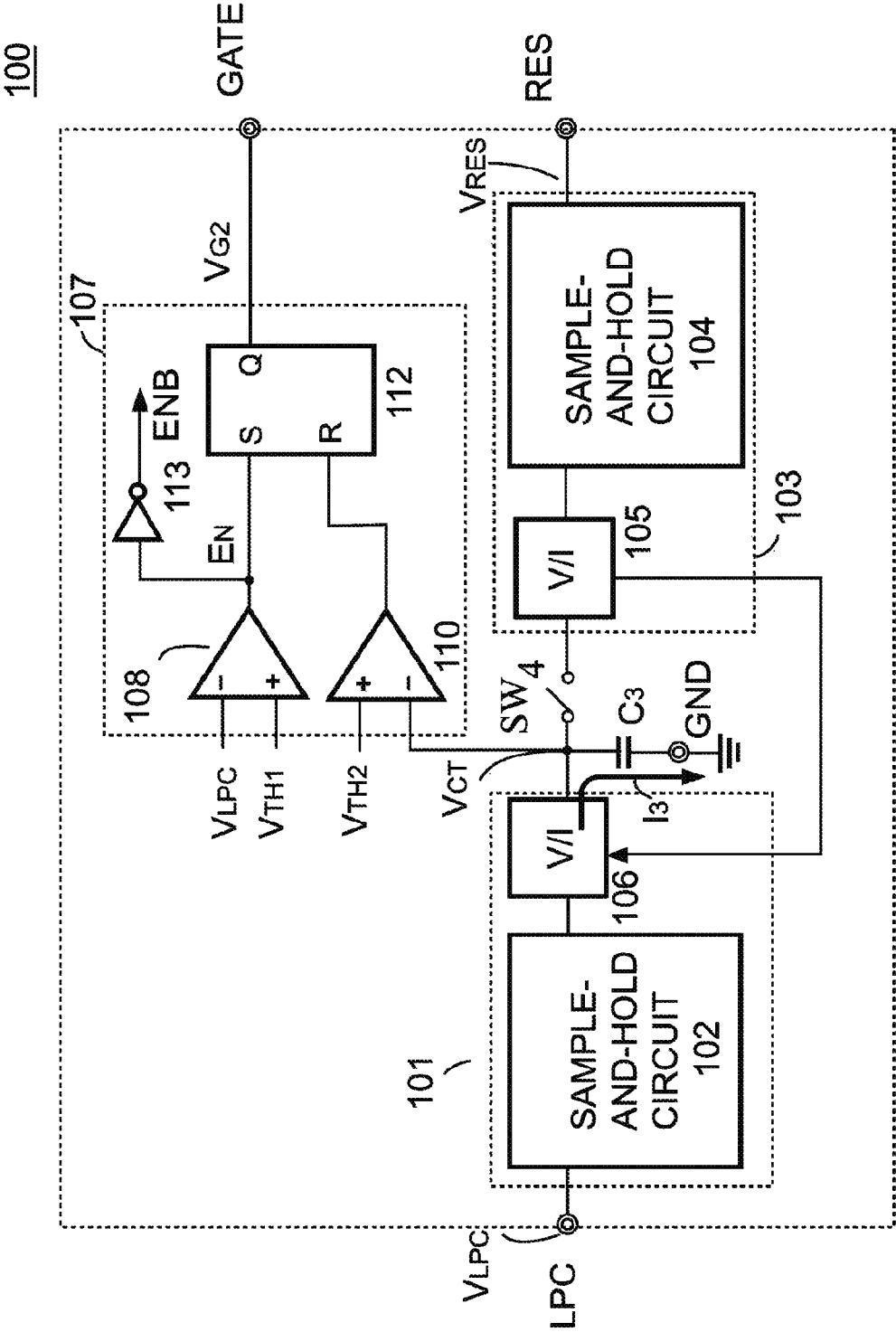


FIG.2A

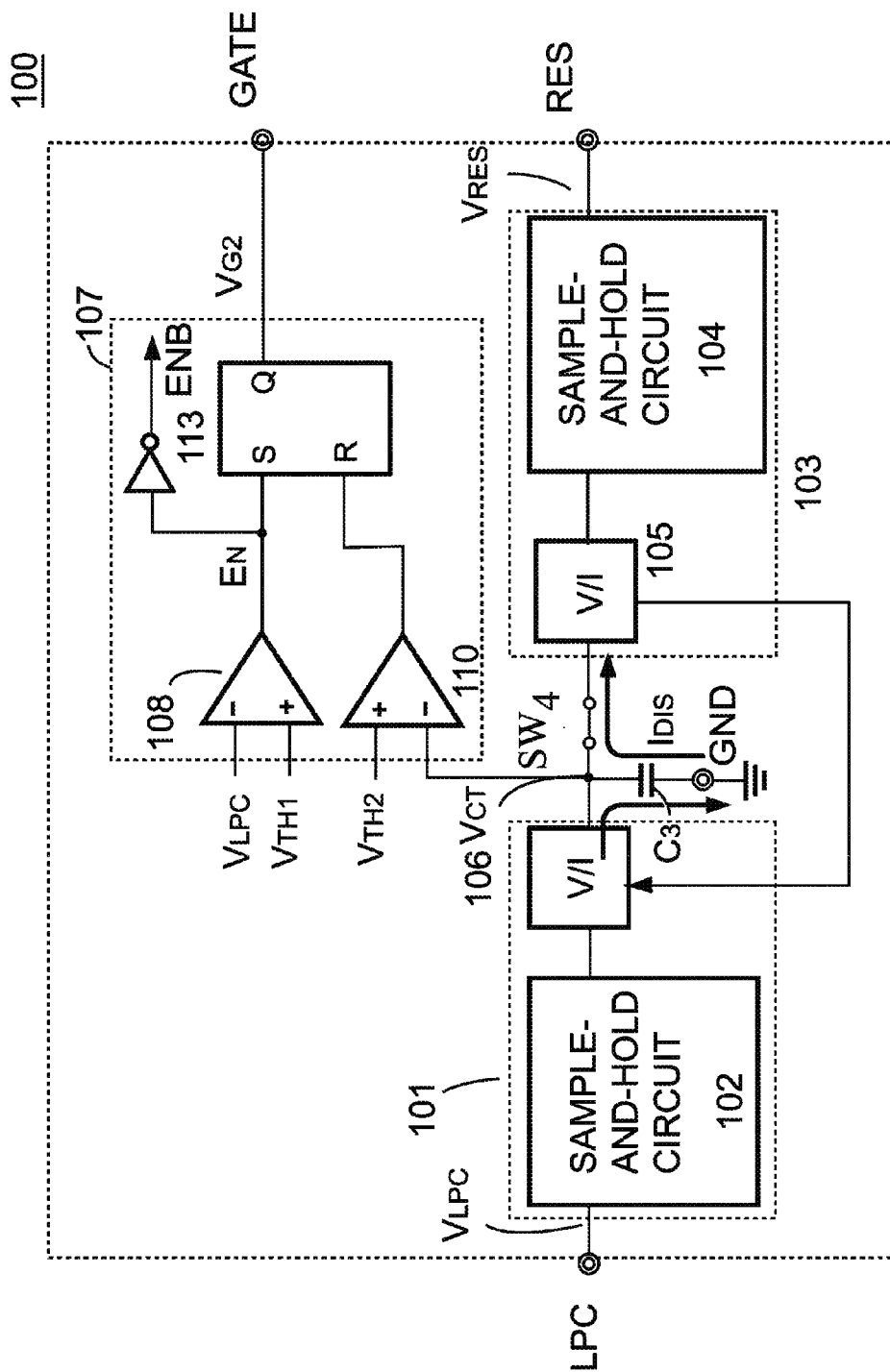


FIG. 2B

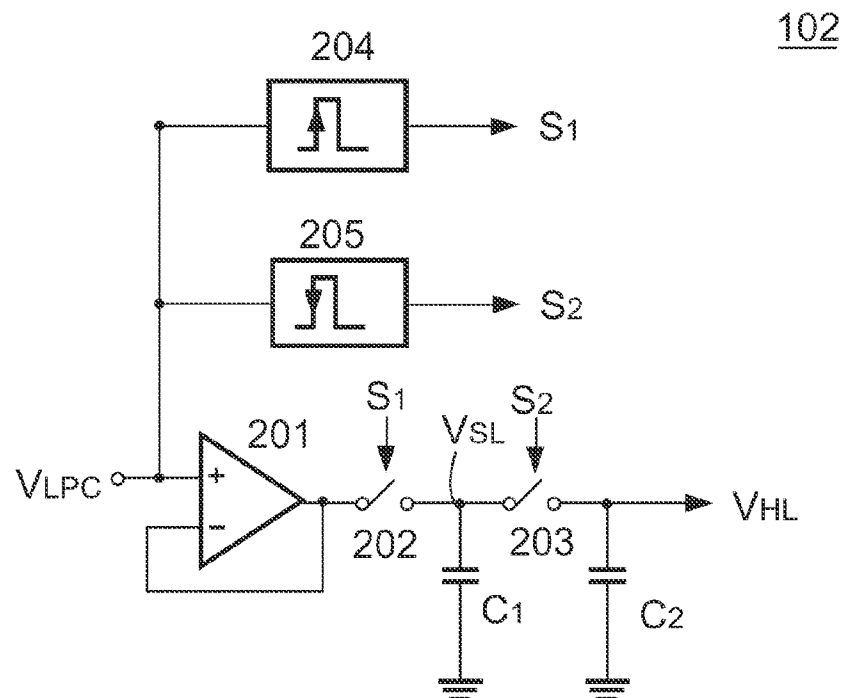


FIG.3

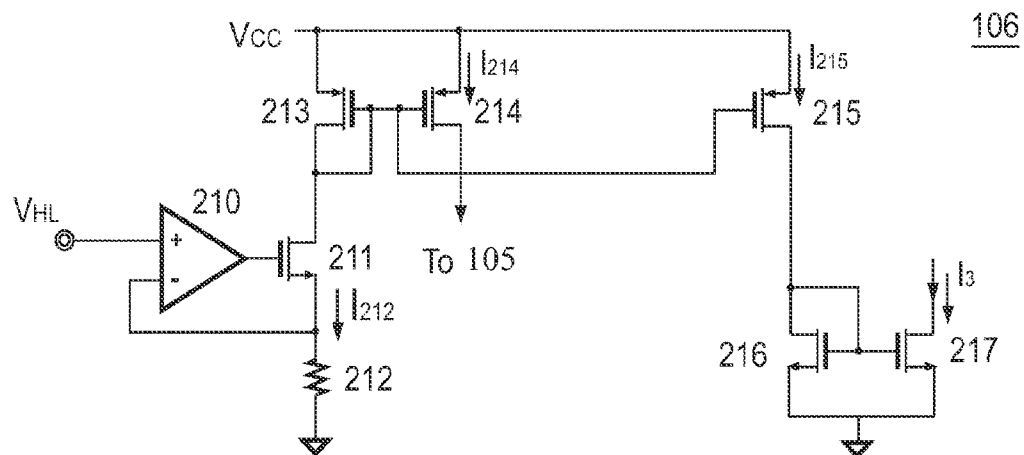


FIG.4

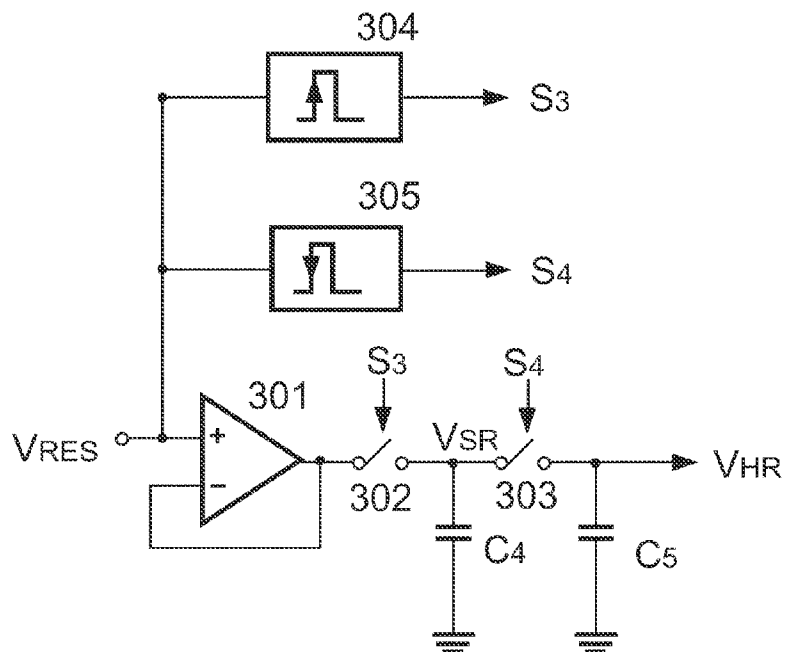


FIG. 5

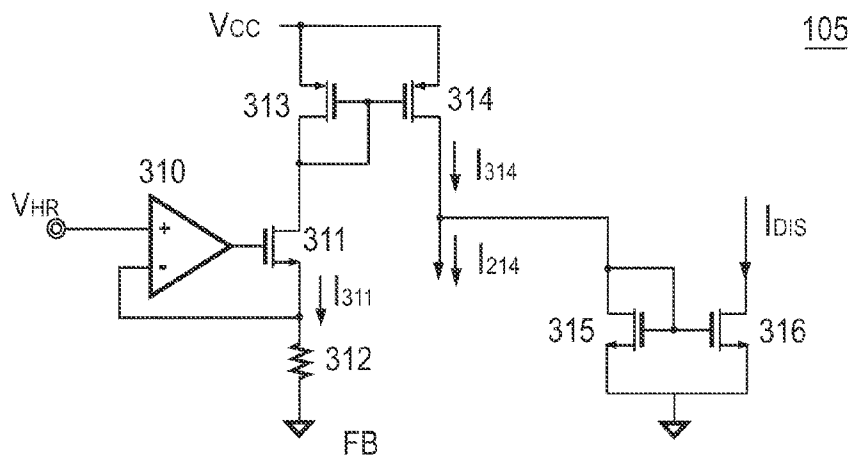


FIG. 6

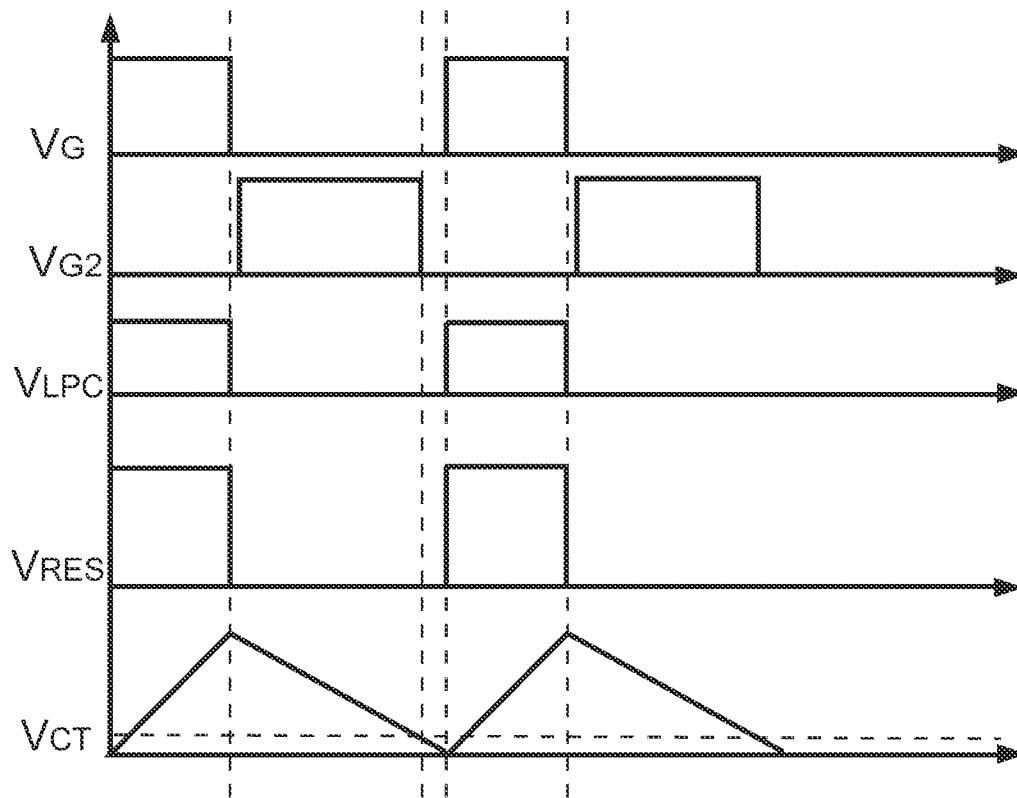


FIG. 7

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HIGH-SIDE SYNCHRONOUS RECTIFIER CIRCUITS AND CONTROL CIRCUITS FOR POWER CONVERTERS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/370,478, filed on Aug. 4, 2010, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to power converters and more particularly, relates to the synchronous rectifier circuits of power converters.

2. Description of the Related Art

A synchronous rectifier controller in nowadays is broadly used to replace really a rectifier for decreasing power loss. A traditional synchronous rectifier controller is installed on the low-side of a secondary side of a power converter. Therefore, a ground terminal of the synchronous rectifier controller is coupled to another ground of the secondary side of the power converter. However, the drawback of the traditional synchronous rectifier controller is that there is switching loss and electric-magnetic-interference (EMI) problem because of the switching operation of the ground of the secondary side of the power converter.

BRIEF SUMMARY OF THE INVENTION

An exemplary embodiment of a control circuit for a switching power converter is provided. The control circuit is installed between a secondary side of the switching power converter and an output of the power converter and coupled to control a switching device. The control circuit comprises a linear predict circuit, a reset circuit, a charge/discharge circuit, and a pulse width modulation (PWM) circuit. The linear predict circuit is coupled to receive a linear predict signal from the secondary side for generating a charging signal. The reset circuit is coupled to receive a resetting signal for generating a discharging signal. The charge/discharge circuit is coupled to receive the charging signal and the discharging signal for generating a ramp signal. The PWM circuit is coupled to receive the linear predict signal for enabling a switching signal and receive the ramp signal for resetting the switching signal.

An exemplary embodiment of a synchronous rectifier circuit for a power converter is provided. The synchronous rectifier circuit comprises a power switching device, a diode, and a control circuit. The power switching device is coupled between a secondary side of the power converter and an output of the power converter for rectifying. The diode is coupled to the power switching device in parallel. The control circuit is installed between the secondary side of the power converter and the output of the power converter. The control circuit is operated to receive a linear predict signal and a ramp signal for turning on/off the power switching device.

A detailed description is given in the following embodiments with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention can be more fully understood by reading the subsequent detailed description and examples with references made to the accompanying drawings, wherein:

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FIG. 1 shows an exemplary embodiment of a switching power converter;

FIGS. 2A and 2B show an exemplary embodiment of a switch controller of the switching power converter in FIG. 1;

FIG. 3 shows an exemplary embodiment of a sample-and-hold circuit of a linear predict circuit in FIGS. 2A and 2B;

FIG. 4 shows an exemplary embodiment of a voltage-to-current converter of a linear predict circuit in FIGS. 2A and 2B;

FIG. 5 shows an exemplary embodiment of a sample-and-hold circuit of a reset circuit in FIGS. 2A and 2B;

FIG. 6 shows an exemplary embodiment of the voltage-to-current converter of a reset circuit in FIGS. 2A and 2B; and

FIG. 7 shows key wave forms of a high-side synchronous rectifier circuit of the switching power converter in FIG. 1.

DETAILED DESCRIPTION OF THE INVENTION

The following description is of the best-contemplated mode of carrying out the invention. This description is made for the purpose of illustrating the general principles of the invention and should not be taken in a limiting sense. The scope of the invention is best determined by reference to the appended claims.

As illustrated in an embodiment of FIG. 1, a transformer T_1 is coupled between an unregulated input voltage V_{IN} and an output V_O of a switching power converter. As shown in FIG. 1, the transformer T_1 comprises a primary winding N_p and two secondary windings N_{S1} and N_{S2} . A power switch Q_1 is coupled to the primary winding N_p at an input of the transformer T_1 to regulate the transfer of energy from the unregulated input voltage V_{IN} to the output V_O of the switching power converter. The power switch Q_1 is coupled to receive a switching signal V_G to control switching of the power switch Q_1 . A resistor **25** is coupled between the power switch Q_1 and a ground of the primary side of the transformer T_1 . A synchronous rectifier circuit **30** is coupled between the high-side of the secondary winding N_{S1} of the transformer T_1 and the output V_O .

The synchronous rectifier circuit **30** is composed of a switching controller **100** which serves as a control circuit for the switching power converter. The switching controller **100** generates a pulse width modulation (PWM) signal V_{G2} which serves as a switching signal for controlling a power transistor Q_2 , wherein the power transistor Q_2 serves as a power switching device for the switching power converter. A diode **40** is connected to the power transistor Q_2 in parallel, wherein the diode **40** is a parasitic diode. The switching controller **100** includes a power terminal VDD, a linear predicting terminal LPC, a reset terminal RES, a ground terminal GND, and a control terminal GATE. The power terminal VDD is coupled to the secondary winding N_{S1} to receive a rectified power source through a diode **45** and a capacitor C_6 . Resistors R_1 and R_2 are coupled in series between the capacitor C_6 and a ground of a secondary side of the transformer T_1 , and a linear predict signal V_{LPC} is generated at the joint of the resistors R_1 and R_2 . Resistors R_3 and R_4 are coupled in series and coupled to the power transistor Q_2 in parallel, and a resetting signal V_{RES} is generated at the joint of the resistors R_3 and R_4 . The linear predicting terminal LPC is coupled to receive the linear predict signal V_{LPC} for charging and the reset terminal RES is coupled to receive the resetting signal V_{RES} for resetting. The control terminal GATE is coupled to generate the PWM signal V_{G2} to control the power transistor Q_2 .

FIGS. 2A and 2B show an exemplary embodiment of the switching controller **100**. The switching controller **100** comprises a linear predict circuit **101**, a reset circuit **103**, a PWM

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circuit **107**, and a charge/discharge circuit. The linear predict circuit **101** is composed of a sample-and-hold circuit **102** and a voltage-to-current converter (V/I) **106**. The reset circuit **103** is also composed of a sample-and-hold circuit **104** and a voltage-to-current converter (V/I) **105**. The charge/discharge circuit comprises a capacitor C_3 and a switch SW_4 . The PWM circuit **107** is composed of an SR-flip-flop **112**, an inverter **113**, and comparators **108** and **110**.

The linear predict circuit **101** is coupled to receive the linear predict signal V_{LPC} for charging to the capacitor C_3 through a sampling-and-hold operation. The linear predict circuit **101** is composed of the sample and hold circuit **102** and the voltage to current converter (V/I) **106**. The sample-and-hold circuit **102** of the linear predict circuit **101** is coupled to receive the linear predict signal V_{LPC} for sampling at a rising edge of the linear predict signal V_{LPC} , and then hold a sampling signal V_{SL} (shown in FIG. 3) at a falling edge of the linear predict signal V_{LPC} to generate a hold signal V_{HL} (shown in FIG. 3). The voltage-to-current converter (V/I) **106** is coupled to generate a charging current (also referred as a charging signal) I_3 in response the hold signal V_{HL} .

The reset circuit **103** is also composed of the sample-and-hold circuit **104** and the voltage-to-current converter (V/I) **105**. The reset circuit **103** is coupled to receive the resetting signal V_{RES} to generate a discharge signal for resetting the PWM circuit **107** through the charge/discharge circuit. The sample-and-hold circuit **104** is coupled to receive the resetting signal V_{RES} for sampling at a rising edge of the resetting signal V_{RES} , and hold the sampling result (sampling signal V_{SR} shown in FIG. 5) at a falling edge of the resetting signal V_{RES} to generate a hold signal V_{HR} (shown in FIG. 5). The voltage-to-current converter (V/I) **105** is coupled to generate a discharging current (also referred as a discharging signal) I_{DIS} in response the hold signal V_{HR} for resetting the PWM circuit **107** through the charge/discharge circuit.

The charge/discharge circuit comprises the capacitor C_3 and the switch SW_4 , which are coupled in series, for receiving the charging current I_3 and receiving the discharging current I_{DIS} through the switch SW_4 . The capacitor C_3 is coupled to receive the charging current I_3 for charging, and the discharging current I_{DIS} is generated from the voltage-to-current converter (V/I) **105** through the switch SW_4 while the switch SW_4 is turned on as shown in FIG. 2B. A ramp signal V_{CT} is thus generated at the joint of the capacitor C_3 and the switch SW_4 in response to the charging current I_3 and the discharging current I_{DIS} .

The SR-flip-flop **112**, the inverter **113**, and the comparators **108** and **110** develop the PWM circuit **107** for generating the PWM signal V_{G2} at the output terminal Q of the SR-flip-flop **112** in response to the linear predict signal V_{LPC} and the ramp signal V_{CT} . The setting terminal S of the SR-flip-flop **112** is controlled by an output of the comparator **108**. The comparator **108** are coupled to receive the linear predict signal V_{LPC} and a first threshold V_{TH1} for comparison. The resetting terminal R of the SR-flip-flop **112** is controlled by an output of the comparator **110**. The comparator **110** is couple to receive the ramp signal V_{CT} and a second threshold V_{TH2} for comparison. The comparator **108** generates an enabling signal E_N according to the comparison result. The inverter **113** is coupled to receive the enabling signal E_N and generate an inverse enabling signal ENB.

FIG. 3 shows an exemplary embodiment of the sample-and-hold circuit **102**. A buffer **201**, a switch **202**, and a capacitor C_1 form a sample circuit, and another switch **203** and a capacitor C_2 form a hold circuit. The linear predict signal V_{LPC} is coupled to generate a first signal S_1 and a second signal S_2 to control the switch **202** and the switch **203** through

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pulse generation circuits **204** and **205**, respectively. The first signal S_1 is enabled in response to the rising edge of the linear predict signal V_{LPC} via the pulse generation circuits **204**, and the second signal S_2 is enabled in response to the falling edge of the predict signal V_{LPC} via the pulse generation circuits **205**. The sampling signal V_{SL} is generated through the switch **202** at the rising edge of the linear predict signal V_{LPC} , and the hold signal V_{HL} is thus generated in the capacitor C_2 at the falling edge of the linear predict signal V_{LPC} . The hold signal V_{HL} is correlated to the high level of the linear predict signal V_{LPC} .

FIG. 4 shows an exemplary embodiment of the voltage-to-current converter (V/I) **106**, wherein an operational amplifier **210**, a transistor **211**, and a resistor **212** develop a V-to-I circuit to generate a current I_{212} in response to the hold signal V_{HL} . Transistors **213**, **214**, **215**, **216**, and **217** develop current mirrors to generate currents I_{214} , I_{215} and I_3 in response to the current I_{212} . The charging current I_3 is proportional to the current I_{212} . The charging current I_3 is coupled to the capacitor C_3 for charging.

FIG. 5 shows an exemplary embodiment of the sample-and-hold circuit **104**. A buffer **301**, a switch **302**, and a capacitor C_4 form a sample circuit, and another switch **303** and a capacitor C_5 form a hold circuit. The resetting signal V_{RES} is coupled to generate a first signal S_3 and a second signal S_4 to control switch **302** and switch **303** through pulse generation circuits **304** and **305**, respectively. The first signal S_3 is enabled in response to the rising edge of the resetting signal V_{RES} via the pulse generation circuits **304**, and the second signal S_2 is enabled in response to the falling edge of the resetting signal V_{RES} via the pulse generation circuits **305**. The sampling signal V_{SR} is generated through the switch S_3 at the rising edge of the resetting signal V_{RES} , and the hold signal V_{HR} is thus generated in the capacitor C_5 at the falling edge of the resetting signal V_{RES} . The hold signal V_{HR} is correlated to the high level of the resetting signal V_{RES} .

FIG. 6 shows an exemplary embodiment of the voltage-to-current converter (V/I) **105**, wherein an operational amplifier **310**, a transistor **311**, and a resistor **312** develop a V-to-I circuit to generate a current I_{311} in response to the hold signal V_{HR} . Transistors **313** and **314** develop a current mirror to generate currents I_{314} in response to the current I_{311} . Other transistors **315** and **316** develop another current mirror to generate the discharging current I_{DIS} in response to the current I_{314} and the current I_{214} from the voltage-to-current converter (V/I) **106**, so the discharging current I_{DIS} can be expressed, $I_{DIS}=I_{314}-I_{214}$.

From the above description, and referring to FIG. 4 to FIG. 6. The current I_{314} is mirrored form the current I_{311} , and the current I_{311} represents the resetting signal V_{RES} . The I_{214} is mirrored form the current I_{212} , and the current I_{212} represents the linear predict signal V_{LPC} . So the discharging current I_{DIS} represents the difference between the resetting signal V_{RES} and the linear predict signal V_{LPC} .

FIG. 7 shows the key wave forms of the high-side synchronous rectifier circuit. Referring to FIG. 2A to FIG. 6, while the switching signal V_G is enabled, the diode **45** and diode **40** are turned off (reversed biased). The voltage of the linear predict signal V_{LPC} is in a high level, which can be express as

$$V_{LPC} = \frac{V_{in}}{n} \times \frac{R_2}{R_1 + R_2},$$

and the PWM signal V_{G2} is disabled in response to the high level of the linear predict signal V_{LPC} at the mean time. The

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power transistor Q_2 is switched off. While the switching signal V_G is disabled, the diode 45 and diode 40 are turned on (forward biased). The PWM signal V_{G2} is enabled in response to the low level of the linear predict signal V_{LPC} . The ramp signal V_{CT} is discharged in response to the difference between the resetting signal V_{RES} and the linear predict signal V_{LPC} . The PWM signal V_{G2} is disabled once the voltage of the ramp signal V_{CT} is lower than the second threshold V_{TH2} .

In summary, the switching controller can be installed at high-side of secondary side of a switching power converter. Therefore, the ground terminal of the switching controller is no more coupled to a ground of low-side of a secondary side of a power converter but coupled to a relative low voltage of the high side winding. So the switching loss and electric-magnetic-interference (EMI) problem caused by the switching operation of the ground of the secondary side of the switching power converter can be solved.

While the invention has been described by way of example and in terms of the preferred embodiments, it is to be understood that the invention is not limited to the disclosed embodiments. To the contrary, it is intended to cover various modifications and similar arrangements (as would be apparent to those skilled in the art). Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

What is claimed is:

1. A control circuit for a switching power converter, the control circuit is installed between a secondary side of the switching power converter and an output of the switching power converter and coupled to control a switching device wherein the control circuit comprises:

- a linear predict circuit, coupled to receive a linear predict signal from the secondary side for generating a charging signal;
- a reset circuit, coupled to receive a resetting signal for generating a discharging signal;
- a charge/discharge circuit, coupled to receive the charging signal and the discharging signal for generating a ramp signal; and
- a pulse width modulation (PWM) circuit, coupled to receive the linear predict signal for enabling a switching signal and receive the ramp signal for resetting the switching signal;

wherein the linear predict circuit comprises:

- a sample-and-hold circuit, coupled to receive the linear predict signal and generate a hold signal in response to the linear predict signal; and
- a voltage-to-current converter, coupled to receive the hold signal and generate the charging signal in response to the hold signal.

2. The control circuit as claimed in claim 1, wherein the reset circuit comprises:

- a sample-and-hold circuit, coupled to receive the resetting signal and generate a hold signal in response to the resetting signal; and
- a voltage-to-current converter, coupled to receive the hold signal and generate the discharging signal in response to the hold signal.

3. The control circuit as claimed in claim 1, wherein the charge/discharge circuit comprises:

- a capacitor, coupled to receive the charging signal and charged by the charging signal; and
- a switch, coupled to the capacitor in series and receiving the discharging signal;

wherein the ramp signal is generated at a joint of the capacitor and the switch in response to the charging signal and the discharging signal.

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4. The control circuit as claimed in claim 1, wherein the PWM circuit comprises:

- a SR-flip-flop, coupled to generate the switching signal in response to the linear predict signal and the ramp signal;
 - a first comparator, coupled to receive the linear predict signal and a first threshold for comparison; and
 - a second comparator, coupled to receive the ramp signal and a second threshold for comparison;
- wherein a setting terminal of the SR-flip-flop is controlled by an output of the first comparator and a resetting terminal of the SR-flip-flop is controlled by an output of the second comparator.

5. A synchronous rectifier circuit for a power converter comprising:

- a power switching device, coupled between a secondary side of the power converter and an output of the power converter for rectifying;
- a diode, coupled to the power switching device in parallel; and
- a control circuit, installed between the secondary side of the power converter and the output of the power converter, wherein the control circuit is operated to receive a linear predict signal and a ramp signal for turning on/off the power switching device;

wherein the control circuit comprises:

- a linear predict circuit, coupled to receive the linear predict signal from the secondary side for generating a charging signal;
- a reset circuit, coupled to receive a resetting signal for generating a discharging signal;
- a charge/discharge circuit, coupled to receive the charging signal and the discharging signal for generating the ramp signal; and
- a pulse width modulation (PWM) circuit, coupled to receive the linear predict signal for enabling a switching signal and receive the ramp signal for resetting the switching signal;

wherein the linear predict circuit comprises:

- a sample-and-hold circuit, coupled to receive the linear predict signal and generate a hold signal in response to the linear predict signal; and
- a voltage-to-current converter, coupled to receive the hold signal and generate the charging signal in response to the hold signal.

6. The synchronous rectifier circuit as claimed in claim 5, wherein the reset circuit comprises:

- a sample and hold circuit, coupled to receive the resetting signal and generate a hold signal in response to the resetting signal; and
- a voltage-to-current converter coupled to receive the hold signal and generate the discharging signal in response to the hold signal.

7. The synchronous rectifier circuit as claimed in claim 5, wherein the charge/discharge circuit comprises:

- a capacitor, coupled to receive the charging signal and charged by the charging signal; and
 - a switch, coupled to the capacitor in series and receiving the discharging signal;
- wherein the ramp signal is generated at a joint of the capacitor and the switch in response to the charging signal and the discharging signal.

8. The synchronous rectifier circuit as claimed in claim 5, wherein the PWM circuit comprises:

- a SR-flip-flop, coupled to generate the switching signal in response to the linear predict signal and the ramp signal;
- a first comparator, coupled to receive the linear predict signal and a first threshold for comparison;

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a second comparator, coupled to receive the ramp signal
and a second threshold for comparison;
wherein a setting terminal of the SR-flip-flop is controlled
by an output of the first comparator and a resetting
terminal of the SR-flip-flop is controlled by an output of 5
the second comparator.

* * * * *

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